Enabling concentrating solar power in Australia: An investigation of the benefits and potential role of concentrating solar power and non-conventional fuel hybrid plants in Australia's transition to a low-carbon energy future

Juergen Heinz Martin Peterseim

Institute for Sustainable Futures

University of Technology, Sydney

Thesis submitted for the PhD in Sustainable Futures

September 2014

STATEMENT OF ORIGINAL AUTHORSHIP

I certify that the work in this thesis has not previously been submitted for a degree and nor has it been submitted as part of the requirements for a degree.

I also certify that the thesis is an original piece of research written by me, except where noted in the text. Any help that I have received in my research work and in the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of candidate:

Juergen Heinz Martin Peterseim

I dedicate this thesis to love and hope:

love for my wife Anja and my children Lola and Leon, and

hope for a bright future for concentrating solar power in Australia.

ACKNOWLEDGEMENTS

Many people supported me in my research and in my personal life throughout this three-year journey. This includes family, friends, supervisors and colleagues, and it would take too long to thank them all individually. In particular I want to thank my wife Anja and my children Lola and Leon for their support as they provided welcome distractions that took my mind off specific research issues. This gave me time to reconsider and in many cases improve my ideas. I know that during this time I did not always have as much time for my family as I wished, and I want to thank Anja for her understanding and efforts to give me time for my research. Without her support this thesis would not exist.

I want to acknowledge my supervisors Prof. Stuart White, Prof. Udo Hellwig and Dr. Amir Tadros for their continual support, their willingness to help and their optimism. I want to thank Prof. Stuart White for his deep insights into sustainability and energy research. His availability, even at short notice, and his detailed feedback allowed me to solve problems quickly and stay on track. I want to thank Prof. Udo Hellwig, not only for his valuable technical support during my candidature, but also for his mentorship since I entered the energy sector in 2003. I don't think I would be in the position I am in today if it had not been for his support. I also want to thank him for the opportunity to work for him part-time during this research project. This was a significant help for me during my second period of time as a student. Last but certainly not least, I want to thank Dr. Amir Tadros for this for valuable insights into techno-economic modelling. His detailed understanding of power plants in the context of the Australian electricity market was invaluable.

Various people within and outside the university contributed to specific aspects of this research. In particular I want to thank Dr. Deborah O'Connell and Dr. Alexander Herr from CSIRO Ecosystems Sciences, and Sarah Miller from CSIRO Energy Technology, for their contribution to the resource assessment, which is a key component of this work. I also want to thank Frank Klostermann, formerly of Thiess Services Pty. Ltd., for his insights into the industry, and for the financial contribution to the Swanbank case study. I sincerely hope that this proposal will eventually turn into an actual power station. I also want to thank various students and staff at ISF for their friendship, support, insightful discussion and time, which not only helped with the thesis but also contributed to my personal development.

Last but not least I want to thank the University of Technology, Sydney for the confidence they showed in me by awarding me a UTS President's Scholarship and two travel funds. Without the scholarship I would not have been able to do this research and the travel funds allowed me to attend relevant international conferences.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PUBLICATIONS

<u>Relevant publications:</u>

- Peterseim J.H., Herr, A., Miller, S., White, S., O'Connell, D.A., 2014, Concentrating solar power/alternative fuel hybrid plants: Annual electricity potential and ideal areas in Australia, *Energy*, vol. 68, pp. 698-711.
- Peterseim, J.H., Hellwig, U., Tadros, A., White, S., 2014. Hybridisation optimization of concentrating solar thermal and biomass power generation facilities. *Solar Energy*, vol. 99, 203–214.
- Peterseim, J. H., Tadros, A., Hellwig, U., White, S., 2014. Increasing the efficiency of parabolic trough plants using thermal oil through external superheating with biomass, *Energy Conversion and Management*, vol. 77, pp. 784–793
- Peterseim, J.H., White, S., Tadros, A., Hellwig, U., 2014. Concentrating solar power hybrid plants - enabling cost effective synergies. *Renewable Energy*, vol. 67, pp. 178-185.
- Peterseim, J.H., White, S., Tadros, A., Hellwig, U., 2013. Concentrated solar power hybrid plants, which technologies are best suited for hybridisation? R*enewable Energy*, vol. 57, 520–532.
- Peterseim, J.H., Tadros, A., White, S., Hellwig, U., Landler, J., Galang, K., 2013. Solar tower-biomass hybrid plants – maximizing plant performance. *Energy Procedia*, vol. 49, no. SolarPACES 2013 conference special, pp. 1197–1206
- Peterseim, J.H., Tadros, A., White, S., Hellwig, U., Klostermann, F., 2012. Concentrated solar power / Energy from Waste hybrid plants - creating synergies. In: *SolarPACES Conference*, Marrakech.
- Peterseim, J.H., White, S., Hellwig, U., Tadros, A., Vanz, E., 2012. Pre-feasibility study for a multi-fuel / concentrated solar power hybrid plant at Swanbank, QLD. Prepared for Thiess Services Pty Ltd by the Institute for Sustainable Futures, University of Technology, Sydney, Unpublished report.

<u>Other publications:</u>

- Peterseim, J.H., Tadros, A., Hellwig, U., White, S., 2013. Integrated solar combined cycle plants using solar towers with thermal storage to increase plant performance. In: *ASME Power Conference*, Boston.
- Peterseim, J.H., Hellwig, U., Endrullat, K., 2013. Parallel flow boiler designs to minimise erosion and corrosion from dust loaded flue gases. In: *ASME Power Conference,* Boston.
- Rutovitz, J., Peterseim, J., Elliston, B., Harris, S., Mohr, S., Lovegrove, K., Want, A., Langham, E., MacGill, I., 2013. Breaking the solar gridlock. Potential benefits of installing concentrating solar thermal power at constrained locations in the NEM. Prepared for the Australian Solar Thermal Energy Association (AUSTELA) by the Institute for Sustainable Futures, UTS, Sydney.
- Peterseim, J.H., White, S., Tadros, A., Hellwig, U., 2012. Integrated Solar Combined Cycle plants using solar power towers to optimise plant performance. In: *SolarPACES Conference*, Marrakech.
- Peterseim, J.H., Hellwig, U., Guthikonda, M., Widera, P., 2012. Quick start-up auxiliary boiler/heater – optimizing solar thermal plant performance. In: *SolarPACES Conference*, Marrakech.
- Baumann, C., Asker, S., Giurco, D., Peterseim, J.H., White, S., 2012. ECO-INDUSTRIAL TRANSITION' A vision for economic and socio-ecological renewal at Swanbank. Prepared for Thiess Services Pty Ltd by the Institute for Sustainable Futures, University of Technology, Sydney, Australia.
- Peterseim, J.H., 2012. Energy Efficiency Opportunity Assessment at Tarong Power Station. Prepared for the Department of Resources, Energy and Tourism by the Institute for Sustainable Futures, Sydney, Unpublished report.
- Memary, R., Giurco, D., Prior, T.D., Mason, L. M., Mudd, G.M., Peterseim, J.H., 2011. Clean energy and mining - future synergies. In: *Second International Future Mining Conference*. The AusIMM (The Mineral Institute), Sydney, Australia.
- Peterseim, J.H., Hellwig, U., 2011. Water circulation calculation for Concentrated Solar Thermal Plants. In: *SolarPACES Conference,* Granada.

LIST OF ABBREVIATIONS

AHP	analytical hierarchy process
ASTRI	Australian solar thermal research initiative
AU$	Australian dollar
b	billion
CapEx	capital expenditure
CO_2	carbon dioxide
CSP	concentrating solar power
DNI	direct normal irradiance
EfB	energy from biomass
EfW	energy from waste
EPC	engineering, procurement and construction
GIS	geographic information system
GWh	gigawatt hour
h	hours
HRSG	heat recovery steam generator
ISCC	integrated solar combined cycle
kW	kilowatt
kWh	kilowatt hour
LCOE	levelised cost of electricity
m	million
MLP	multi-level perspective
MSW	municipal solid waste
MW	megawatt
MWh	megawatt hour
MWth	Megawatt thermal
NEM	national electricity market
OpEx	operational expenditure
PPA	power purchase agreement
PV	photovoltaic
R&D	research and development
RDF	refused derived fuels
RECs	renewable energy certificates
RET	renewable energy target
SEGS	solar energy generation systems
SNM	strategic niche management
SRF	solid recovered fuels
t	tonnes
t/h	tonnes per hour
TES	thermal energy storage
TWh	terrawatt hour
US$	U.S. dollar

ABSTRACT

After decades of stability the Australian electricity market is undergoing changes. Current government targets aim to reduce greenhouse gas emissions by 5% and raise renewable electricity production to 45 TWh by 2020. In addition, increases to natural gas prices, aging generation assets and falling electricity demand have had an impact in recent years.

Uncertainties exist around current policies, including the carbon pricing mechanism and the renewable energy target, but in light of Australian and international ambitions to lower greenhouse gas emissions the deployment of renewable energy technologies is essential. In recent years wind and photovoltaic installations have shown the highest renewable energy growth rates while concentrating solar power has struggled, despite Australia having some of the best natural resources for concentrating solar power in the world and some selected government funding. Reasons for the slow uptake include the comparatively high cost and lack of financial incentives. While technology costs are expected to decrease by up to 40% by 2020 through deployment as well as research and development, other cost reduction options have to be identified to promote short-term implementation in electricity markets such as Australia where the wholesale cost is low. To overcome the cost problem and to address other relevant implementation barriers this research analyses the hybridisation of concentrating solar power with biomass and waste feedstocks.

The results of this research include:

- a recommendation for a categorisation system for CSP hybrid plants based on the degree of interconnection of the plant components
- the availability of combined resources to generate up to 33.5 TWh per year and abate 27 million tonnes CO_2 annually
- an analysis of the most suitable CSP technologies for hybridisation
- a technology comparison showing CSP cost reductions through hybridisation of up to 40%
- the identification of cost differences of up to 31% between different hybrid concepts
- an analysis showing that the current economic and policy settings are the most significant implementation barriers
- two case studies with different biomass and waste feedstocks requiring power purchase agreements of AU$ 100-155/MWh.

Based on the various benefits of concentrating solar power hybrid plants, this research analyses the potential role of this technological pairing in Australia's transition to a low carbon energy future. The research concludes that concentrating solar power hybrid plants, not only hybridised with biomass and waste feedstocks, can immediately enable a lower cost deployment of concentrating solar power facilities in Australia. The technology, deployment and operation of the first hybrid installations would provide market participants with valuable lessons and would have the potential to reconfigure the electricity market towards more sustainable generation. This could help promote the development of future low-cost concentrating solar power plants in Australia.

FOREWORD

When I started considering a PhD candidature in 2010 I already had a few potential topics in mind that derived from observations I had made since entering the energy business in 2003. I worked as an industrial engineer in several areas, including project management and business development, for the German boiler design companies La Mont-Kessel GmbH & Co. KG and ERK Eckrohrkessel GmbH. This allowed me to develop a detailed understanding of current issues with solid, liquid and gaseous fuel fired water tube boiler systems, and of their impact on power plant efficiency, reliability and cost. My early focus was on energy from biomass and from waste systems as well as work on compact boiler and heat exchanger systems. After moving to Australia in 2007 I continued work in these fields but also expanded into heat recovery and natural gas fired boilers.

The good resource for solar energy in Australia, and my interest in Rankine cycle systems, shifted my attention to concentrating solar power. The technology was immediately appealing due to its futuristic appearance, its low carbon intensity, and the availability of mature equipment for most of the plant. In late 2010 I was awarded a UTS scholarship and since commencing this research in March 2011 my interest in concentrating solar power has continued to grow. The work I have done for my PhD has enabled me to expand my knowledge not only through theoretical work, such as a literature review and thermo-economic modelling, but also through the exchange of ideas and cooperation with industry partners, both those I had known previously and others I have met during the last three years.

I sincerely hope that this thesis will contribute to the deployment of concentrating solar power plants in Australia and I am looking forward to further engaging with the technology for the foreseeable future.